

**WE CLAIM:**

1. A very narrow band two chamber high repetition rate  $F_2$  gas discharge laser system comprising:

- A) a first laser unit comprising:
  - 1) a first discharge chamber containing:
    - a) a first laser gas
    - b) a first pair of elongated spaced apart electrodes defining a first discharge region,
  - 2) a first fan for producing sufficient gas velocities of said first laser gas in said first discharge region to clear from said first discharge region, following each pulse, substantially all discharge produced ions prior to a next pulse when operating at a repetition rate in the range of 4,000 pulses per second or greater,
  - 3) a first heat exchanger system capable of removing at least 16 kw of heat energy from said first laser gas,
- B) a line selection unit for minimizing energy outside of a single selected line spectrum,
- C) a second laser unit comprising:
  - 1) a second discharge chamber containing:
    - a) a second laser gas,
    - b) a second pair of elongated spaced apart electrodes defining a second discharge region
  - 2) a second fan for producing sufficient gas velocities of said second laser gas in said second discharge region to clear from said second discharge region, following each pulse, substantially all discharge produced ions prior to a next pulse when operating at a repetition rate in the range of 4,000 pulses per second or greater,

- 3) a second heat exchanger system capable of removing at least 16 kw of heat energy from said second laser gas,
- D) a pulse power system configured to provide electrical pulses to said first pair of electrodes and to said second pair of electrodes sufficient to produce laser pulses at rates of about 4,000 pulses per second with precisely controlled pulse energies in excess of about 5 mJ,
- E) a laser beam measurement and control system for measuring pulse energy of laser output pulses produced by said two chamber laser system and controlling said laser output pulses in a feedback control arrangement, and

wherein output laser beams from said first laser unit are utilized as a seed beam for seeding said second laser unit.

2. A laser system as in Claim 1 wherein said first laser unit is configured as a master oscillator and said second laser unit is configured as a power amplifier.

3. A laser system as in Claim 2 wherein said first laser gas comprises fluorine and neon.

4. A laser system as in Claim 2 wherein said first laser gas comprises fluorine and helium.

5. A laser system as in Claim 2 wherein said first and second laser gas comprises fluorine and a buffer gas chosen from a group consisting of neon, helium or a mixture of neon and helium.

6. A laser system as in Claim 2 wherein said power amplifier is configured for a single beam pass through the second discharge region.

7. A laser system as in Claim 2 wherein said power amplifier is configured for a plurality of passes through the second discharge region.

8. A laser as in Claim 2 wherein said master oscillator comprises optical components providing a resonant path making two passes through said first discharge region.

9. A laser as in Claim 2 wherein said master oscillator comprises optical components providing a resonant path making two passes through said first discharge region and wherein said power amplifier comprises optical components providing a plurality of beam passes through the second discharge region

10. A laser system as in Claim 1 and further comprising an optical table for supporting resonant cavity optics of said first laser unit independent of said first discharge chamber.

11. A laser system as in Claim 10 wherein said optical table is generally U-shaped and defines a U-cavity and wherein said first discharge chamber is mounted within the U-cavity.

12. A laser as in Claim 1 and further comprising a vertically mounted optical table with said first and second discharge chambers mounted on said vertical optical table.

13. A laser system as in Claim 1 wherein each of said first and second laser chambers define a gas flow path with a gradually increasing cross section downstream of said electrodes to permit recovery of a large percentage of static pressure drop occurring in the discharge regions.

14. A laser as in Claim 2 and wherein first and second said chambers each comprises a vane structure downstream of said discharge region for normalizing gas velocity downstream of said discharge region.

15. A laser as in Claim 1 wherein said first fan and said second fan each are tangential fans and each comprises a shaft driven by two brushless DC motors.

16. A laser as in Claim 15 wherein said motors are water cooled motors.

17. A laser as in Claim 15 wherein each of said motors comprise a stator and each of said motors comprise a magnetic rotor contained in a pressure cup separating a said stator from said laser gas.

18. A laser as in Claim 1 wherein said first and second fans are each tangential fans each comprising a blade structure machined from said aluminum stock.

19. A laser as in Claim 15 wherein said blade structure has an outside diameter of about five inches.

20. A laser as in Claim 19 wherein said blade structures comprise blade elements having sharp leading edges.

21. A laser as in Claim 15 wherein said motors are sensorless motors and further comprising a master motor controller for controlling one of said motors and a slave motor controller for controlling the other motor.

22. A laser as in Claim 15 wherein each of said tangential fans comprise blades which are angled with respect to said shaft.

23. A laser as in Claim 1 wherein each finned heat exchanger system is water cooled.

24. A laser as in Claim 23 wherein each heat exchanger system comprises at least four separate water cooled heat exchangers.

25. A laser as in Claim 23 wherein each heat exchanger system comprises at least one heat exchanger having a tubular water flow passage wherein at least one turbulator is located in said path.

26. A laser as in Claim 25 wherein each of said four heat exchangers comprise a tubular water flow passage containing a turbulator.

27. A laser as in Claim 1 wherein said pulse power system comprise water cooled electrical components.

28. A laser as in Claim 27 wherein at least one of said water cooled components is a component operated at high voltages in excess of 12,000 volts.

29. A laser as in Claim 28 wherein said high voltage is isolated from ground using an inductor through which cooling water flows.

30. A laser as in Claim 1 wherein said pulse power system comprises a first charging capacitor bank and a first pulse compression circuit for providing electrical pulses to said first pair of electrodes and a second charging capacitor bank and a second pulse compression circuit for providing electrical pulses to said second pair of electrodes and a resonant charging system to charge in parallel said first and second charging capacitor banks to a precisely controlled voltage.

31. A laser as in Claim 30 wherein said resonance charging system comprises a De-Qing circuit.

32. A laser as in Claim 30 wherein said resonance charging system comprises a bleed circuit.

33. A laser as in Claim 30 wherein said resonant charging system comprises a De-Qing circuit and a bleed circuit.

34. A laser as in Claim 1 wherein said pulse power system comprises a charging system comprised of at least three power supplies arranged in parallel.

35. A laser as in Claim 1 wherein said line selection unit is located downstream of said master oscillator.

36. A laser as in Claim 35 wherein said line selection unit comprises a plurality of prisms.

37. A laser as in Claim 36 wherein said plurality of prisms is five prisms.

38. A laser as in Claim 36 wherein said plurality of prisms are arranged in a loop so as to cause laser beams from the first laser unit to make a 360° turn prior to entering the second laser unit.

39. A laser as in Claim 1 and further comprising a visible light alignment laser.

40. A laser as in Claim 1 wherein said line selection unit comprises a Lyot filter.

41. A laser as in Claim 1 wherein said first discharge chamber and said second discharge chamber comprise chamber windows positioned so that the incident angles of laser beams on said windows are all greater than Brewster' angle.

42. A laser as in Claim 1 and further comprising a beam steering means for steering laser beams produced in said first laser unit.

43. A laser as in Claim 42 wherein said steering means comprises a means for pivoting an optical element.

44. A laser as in Claim 42 wherein said beam steering means comprises a means for adjusting the pressure in said line selection unit.

45. A laser as in Claim 1 wherein said laser system comprises prism output coupler in part defining a resonant cavity for said first laser unit, said prism output coupler comprises two surfaces, a first surface oriented at a low loss angle for p-polarization and a second surface located orthogonal to laser beams from said first laser unit.

46. A laser as in Claim 1 and further comprising:

- A) a first temperature monitor for monitoring gas temperature in said first discharge chamber,
- B) a first gas temperature control system where gas temperature control system comprises a control algorithm for adjusting gas temperature to avoid adverse acoustic effects resulting from reflected acoustic waves.

47. A laser as in Claim 1 and further comprising:

- A) a second temperature monitor for monitoring gas temperature in said second discharge chamber,
- B) a second gas temperature control system where gas temperature control system comprises a control algorithm for adjusting gas temperature to avoid adverse acoustic effects resulting from reflected acoustic waves.

48. A laser as in Claim 1 and further comprising a nitrogen filter.

49. A laser as in Claim 1 and further comprising a nitrogen purge system comprising a purge module comprising flow monitors said laser also comprising purge exhaust tubes for transporting exhaust purge gas from said laser.

50. A laser as in Claim 1 and further comprising a shutter unit comprising an electrically operated shutter and a power meter which can be positioned in a laser output beam path with a command signal.

51. A laser as in Claim 51 and further comprising a beam enclosure system comprising:

- A) at least one beam seal said beam seals comprising a metal bellows, and
- B) a purge means for purging said beam enclosure with a purge gas.

52. A laser as in Claim 51 wherein said beam enclosure means comprise a flow directing means for producing purge flow transverse to laser beams produced in said second laser unit.

53. A laser as in Claim 51 wherein said at least one beam seal is configured to permit easy replacement of said laser chamber.

54. A laser as in Claim 51 wherein said at least one beam seal contains no elastomer, provide vibration isolation from said chamber, provide beam train isolation from atmospheric gases and permit unrestricted replacement of said laser chamber without disturbance of said line selection unit.

55. A laser as in Claim 51 wherein said at least one beam seal is vacuum compatible.



56. A laser as in Claim 55 wherein said at least one beam seal is a plurality of beam seals and said plurality of said seals are easy sealing bellows seals configured for easy removal by hand.

57. A laser as in Claim 1 wherein said measurement and control system comprises a primary beam splitter for splitting off a small percentage of output pulses from said second laser unit and an optical means for directing a portion of said small percentage to said pulse energy detector and an isolation means for isolating a volume bounded at least in part by said primary beam splitter and a window of said pulse energy detector from other portions of said measurement and control system to define an isolated region.

58. A laser as in Claim 57 and further comprising a purge means for purging said isolated region with a purge gas.

59. A laser system as in Claim 1 wherein said system is configured to operate either of a KrF laser system, an ArF laser system or an F<sub>2</sub> laser system with minor modifications.

60. A laser system as in Claim 1 wherein substantially all components are contained in a laser enclosure but said system comprises an AC/DC module physically separate from the enclosure.

61. A laser system as in Claim 1 wherein said pulse power system comprises a master oscillator charging capacitor bank and a power amplifier charging capacitor bank and a resonant charger configured to charge both charging capacitor banks in parallel.

62. A laser as in Claim 61 wherein said pulse power system comprises a power supply configured to furnish at least 2000V supply to said resonant charges.

63. A laser as in Claim 1 and further comprising a gas control system for controlling F<sub>2</sub> concentrations in said first laser gas to control master oscillator beam parameters.

64. A laser as in Claim 1 and further comprising a gas control system for controlling laser gas pressure in said first laser gas to control master oscillator beam parameters.

65. A laser as in Claim 2 and further comprising a discharge timing controller for triggering discharges in said power amplifier to occur between 20 and 60 ns after discharges in said master oscillator.

66. A laser as in Claim 2 and further comprising a discharge controller programmed to cause in some circumstances discharges so timed to avoid any significant output pulse energy.

67. A laser as in Claim 66 wherein said controller in said some circumstances is programmed to cause discharge in said power amplifier at least 20 ns prior to discharge in said master oscillator.

68. A laser as in Claim 1 and further comprising a pulse multiplier unit for increasing duration of output pulses from said laser.

69. A laser as in Claim 68 wherein pulse multiplier unit is arranged to receive said output pulse laser beam and to multiply the number of pulses per second by at least a factor of two so as to produce a single multiplier output pulse beam comprised of a larger number of pulses with substantially reduced intensity values as compared with the laser output pulses, and pulse multiplier unit comprising:

- (1) a first beam splitter arranged to separate a portion of said output beam, the separated portion defining a delayed portion, and the output beam defining a

- beam size and angular spread at said first beam splitter;
- (2) a first delay path originating and terminating at said first beam splitter said first delay path comprising at least two focusing mirrors, said mirrors being arranged to focus said delayed portion at a focal point within said first delay path and to return said delayed portion to said first beam splitter with a beam size and angular spread equal to or approximately equal to the beam size and angular spread of the output beam at said first beam splitter.

70. A laser system as in Claim 69 wherein said at least two focusing mirrors are spherical mirrors.

71. A laser system as in Claim 69 and further comprising a second delay path comprising at least two spherical mirrors.

72. A laser system as in Claim 69 wherein said first delay path comprises four focusing mirrors.

73. A laser system as in Claim 72 and further comprising said second delay path created by a second beam splitter located in said first delay path.

74. A laser as in Claim 69 wherein said first delay path comprises a second beam splitter and further comprising a second delay path comprising at least two focusing mirrors, said mirrors being arranged to focus said delayed portion at a focal point within said first delay path and to return said delayed portion to said first beam splitter with a beam size and angular spread equal to or approximately equal to the beam size and angular spread of the output beam at said first beam splitter.

75. A laser as in Claim 69 wherein said first beam splitter is configured to direct a laser beam in at least two directions utilizing optical property of frustrated internal reflection.

76. A laser as in Claim 69 wherein said first beam splitter is comprised of two transparent optical elements each element having a flat surface, said optical elements being positioned with said surfaces parallel to each other and separated by less than 200 nm.

77. A laser as in Claim 69 wherein said first beam splitter is an uncoated optical element oriented at an angle with said output laser beam so as to achieve a desired reflection-transmission ratio.